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TITLE:                        **FLUID FLOW METER**

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## **FLUID FLOW METER**

### **TECHNICAL FIELD**

**[0001]** The present invention relates to devices and methods for measuring fluid flow in a duct.

### **BACKGROUND OF THE INVENTION**

**[0002]** Internal combustion engines today include electronic controls to provide optimal engine operation. Typically, the electronic control systems include a primary control unit for processing control algorithms and a variety of sensors for providing control signals to the primary control unit. One critically important sensor for achieving optimal engine control is a mass fluid flow sensor for measuring air intake into the internal combustion engine.

**[0003]** It is critical that the mass fluid flow measurement is accurate in order to provide optimal engine operation. One significant problem affecting the mass fluid flow measurement, is reverse flow or back flow in the direction opposite of fluid intake. Typically, mass fluid flow sensors detect the flow of air in both the forward and reverse directions relative to air intake, therefore reverse flow causes an inaccurate mass fluid flow reading.

**[0004]** Prior art mass fluid/air flow devices have attempted to address this problem by providing mass air flow sensor configured as disclosed in U.S. Patent No. 5,556,340 issued to Clowater et al. In Clowater, a mass air flow sensor having a U-shaped air passage and a longitudinally converging elliptical inlet configuration is disclosed, and hereby incorporated by reference. This configuration increased measurement efficiency and reduced the effect of back flow on the measurement of air flow into the internal combustion engine. Further, such a configuration produces advantageously low signal to noise ratio, as well as high velocity across the mass fluid flow sensor element.

**[0005]** While prior art mass fluid flow sensors, such as the one disclosed in Clowater, significantly improved the accuracy of the mass fluid flow measurement. Improvements are still needed to address other problems.

**[0006]** For example, it would be advantageous to provide a mass fluid/air flow sensor having improved response time, a more aero-dynamic design, having a lower system pressure drop, an improved internal flow passage pressure drop, in improved signal to noise ratio, an improved electromagnetic interference performance, and fewer parts to achieve less manufacturing complexity.

#### **BRIEF SUMMARY OF THE INVENTION**

**[0007]** In an embodiment of the present invention, a mass fluid flow sensor is provided for determining the amount of air inducted into an internal combustion engine, in accordance with the present invention. The mass fluid flow sensor of the present invention includes an external intake air temperature element which improves the accuracy of the mass air reading. An external cold wire element is further provided which improves response time. The mass fluid flow sensor of the present invention has an improved aerodynamic design which provides a lower system pressure drop. Moreover, the sensor is smaller and lighter and has fewer parts, thus providing a better manufacturability. For example, a molded one-piece isolated jet nozzle having a hot element disposed therein is provided in a flow passage of the sampling portion of the housing. Consequently, an improved lower internal flow passage pressure drop is achieved. Additionally, an improved signal to noise ratio, as well as a larger dynamic range is an advantageous consequence of the present invention. The present invention further provides improved electromagnetic interference performance.

**[0008]** In an embodiment of the present invention, a mass fluid flow sensor having a circular opening or inlet of the nozzle is provided.

**[0009]** In another embodiment of the present invention, control electronics are located in a longitudinally extending section of the mass fluid flow sensor housing above the sampling portion. Thus, the present invention provides an integrated circuit cavity and sampling portion in one package.

**[0010]** In another aspect of the present invention, a U-shaped flow passage is provided for capturing a sample of the intake air.

**[0011]** In yet another embodiment of the present invention, an outlet of the U-shaped flow passage is provided to allow the fluid to exit and flow out of the bottom of the flow passage, as well as, the sides of the housing.

**[0012]** In yet another embodiment of the present invention, a measuring element is located within the flow passage at the exit or outlet of the jet nozzle, in accordance with the present invention.

**[0013]** In yet another aspect of the present invention, the measuring element is centered at the exit of the converging nozzle.

**[0014]** In still another embodiment of the present invention, the control electronics are located adjacent the flow passage within the circuit cavity.

**[0015]** Further objects, features and advantages of the invention will become apparent from consideration of the following description and the appended claims when taken in connection with the accompanying drawings.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

**[0016]** Figure 1 is an exploded view of a mass fluid flow sensor in accordance with the present invention;

**[0017]** Figure 2 is a perspective view of a mass fluid flow housing in accordance with the present invention;

**[0018]** Figure 3 is a perspective view of a mass fluid flow housing cover, in accordance with the present invention;

**[0019]** Figure 4a is an inside perspective view of a mass fluid flow housing cover, in accordance with the present invention;

**[0020]** Figure 4b is an outside perspective view of the housing with the housing cover installed thereon, in accordance with the present invention;

**[0021]** Figure 4c is a perspective view of the housing with the housing cover installed thereon, in accordance with the present invention;

**[0022]** Figure 5 is a perspective inside view of an electronics cover for a mass fluid flow sensor, in accordance with the present invention;

**[0023]** Figure 6 is an outside view of an electronics cover of a mass fluid flow sensor, in accordance with the present invention;

**[0024]** Figure 7a is a fully assembled perspective view of a mass fluid flow sensor in accordance with the present invention;

**[0025]** Figure 7b is a cross-sectional view through the mass fluid flow sensor as indicated in Figure 7a in accordance with the present invention; and

**[0026]** Figure 8 is cross-sectional view through an automotive fluid intake manifold and further illustrated in exemplary location of the mass fluid flow sensor, in accordance with the present invention.

#### **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT**

**[0027]** Referring now to Figures 1 and 2, exploded and perspective views of a mass fluid flow sensor 10 for calculating the amount of fluid flowing in a duct is illustrated, in accordance with the present invention. One application or use for sensor 10 is for measuring the amount of air inducted into an internal combustion engine (not shown). However, the present invention contemplates other uses and application for sensor 10. For example, sensor 10 may be used to calculate the amount of fluid (other than air) flowing through a duct (other than an air intake duct of an internal combustion engine). Mass fluid flow sensor 10 includes a housing 12, housing cover 14, a secondary housing cover 16, an electronics cover 18, and a gasket 20.

**[0028]** Housing 12 includes an integral connector 30 having connector terminals (not shown) that are in electrical communication with engine operation control electronics external to mass fluid flow sensor 10 and in electrical communication with a circuit module 32 disposed within a central housing portion 34. Adjacent to central housing portion 34, housing 12 further provides an integrally attached fluid sampling portion 36. Fluid sampling portion 36 includes an inlet 38 that opens into a nozzle 39. Nozzle 39 communicates with a substantially U-shaped flow passage 40. U-shaped flow passage 40 terminates at an outlet 42.

**[0029]** Nozzle 39 has, generally, a jet nozzle configuration or shape. As will be further illustrated and described, nozzle 39 is defined by a generally circular opening or inlet 38 that meets longitudinally converging elliptical side surfaces (as shown in Figure 7b). The longitudinally converging elliptical side surfaces of the nozzle create a relatively high pressure at an exit 41 of nozzle 39. Further, the jet

nozzle configuration of nozzle 39 creates a critical area 43 located at exit 41 having a uniform fluid flow velocity across the critical area. This critical area created by the nozzle provides enhanced fluid flow detection and measurement as will be described hereinafter. To further enhance the flow of fluid through passage 40 a wedge deflector 45 is positioned on an end of housing 12 upstream of outlet 42. Wedge deflector 45 has a surface that is tilted to create an advantageously low pressure area adjacent outlet 42. If the angle of the surface of deflector 45 (indicated by the letter  $\alpha$  in Figure 7b) is too small with respect to the direction of fluid flow an insufficient pressure drop is created at outlet 42. Conversely, if the angle of the surface of deflector 45 is too large with respect to the direction of fluid flow an insufficient pressure drop is created at outlet 42.

**[0030]** As illustrated in Figure 2, a plurality of resistive elements are operatively disposed and supported by housing 12 and are in electrical communication with circuit module 32 via electrical conductors, such as integrally molded leads or terminals. The resistive elements include a hot wire element 44, a cold wire element 46 and an internal fluid temperature (IAT) element 48. Generally, these elements change resistance as a function of temperature.

**[0031]** Circuit module 32 senses a fluid, such as, air flowing through passage 40 by monitoring the power dissipated by the elements. Circuit module 32 may be a single integrated circuit chip or a substrate having discrete, as well as, integrated circuits mounted thereon. The sensed resistance change in the elements is converted to an output signal that is received by the electronic engine control system (not shown). Typically, the electronic engine control system regulates the quantity of fuel injected into the engine by controlling the air to fuel ratio.

**[0032]** The IAT or element 48 is generally a thermister or similar device. Element 48 is located on housing 12 to insure an accurate reading of the temperature of the air charge during the induction cycle of the internal combustion engine. As shown in Figure 2, element 48 is located, preferably, external of passage 40 to minimize the fluid heating effects caused by the heat dissipation from hot element 44.

**[0033]** In a preferred embodiment of the present invention, a fluid flow sensor 10 is provided having elements 44 and 46 made of platinum wire wound resistors. Generally, these elements have a positive temperature coefficient. Thus, any resistive changes in the elements will correspond with a temperature change in the same direction. That is, if the temperature increases, the resistance will increase, and if the temperature decreases, the resistance will decrease. Preferably, hot element 44 is located at exit 41 of nozzle 39 and within the critical area 43. The location of the hot element within the critical area insures that fluid, having the same velocity, flows over the hot element causing heat to dissipate evenly across the entire surface of the element. Thus, the present invention provides enhanced fluid flow detection.

**[0034]** In an embodiment of the present invention, hot element 44 may for example have a resistance of 20 Ohms at 70° F. Thus, if the temperature increases by 1° F the resistance of the hot wire will increase by approximately 0.025 Ohms. The hot element 44 is used primarily for detecting the velocity of the fluid flowing through passage 40 from which the mass of fluid flowing through passage 40 may be derived.

**[0035]** The cold wire element 46, may for example have a nominal resistance of 500 Ohms at 70° F. If the temperature of the cold wire is increase by 1° F the resistance of cold wire will increase by approximately 0.5 Ohms. The primary purpose of the cold wire element 46 is to provide temperature correction.

**[0036]** In operation hot wire element 44 is held at approximately 200° F above the ambient temperature. This is accomplished by placing the hot wire element in a voltage divider circuit. With reference to Figure 3, an exemplary voltage divider circuit 500 for fixing hot wire element 44 at a desired constant resistance and temperature is illustrated, in accordance with the present invention. In an embodiment of the present invention circuit 500 is disposed in integrated circuit 32, along with other control circuitry. Exemplary circuit 500 includes two voltage divider networks 502 and 504 in communication with an operational amplifier 506. Voltage divider network 502 generally has two 500 Ohm resistors 508 and 510 which form a 50% voltage divider network and force plus pin 512 of op-amp 506 to half the output

voltage on line 518. The other voltage divider network 504 includes generally a 25 Ohm resistor 514 in series with the hot wire element 44. The minus pin 516 of op-amp 506 is connected between resistor 514 and hot wire element 44. Thus the ratio of this network starts with a ratio of 20 Ohms to 45 Ohms, so minus pin 516 is forced to  $20/45^{\text{th}}$  of the output voltage. For example, the op-amps output voltage on output line 518 will increase if the voltage on plus pin 512 is greater than the voltage on the minus pin 516. Likewise, the output voltage on line 518 will decrease if the voltage on plus pin 512 is less than the voltage on minus pin 516. Accordingly, the op-amp's output voltage on line 518 will increase or decrease by a voltage amount necessary to force the voltage on plus pin 512 to equal the voltage on minus pin 516.

**[0037]** Since resistor network 502 provides a greater voltage on plus pin 512 that is 50% of the output voltage as compared to 44% on minus pin 516, the op-amps output voltage will increase on line 518. As the voltage increases, the power dissipated by the hot wire element 44 causes an increase in resistance of the hot element. It takes approximately one quarter watt of power in still air to increase the temperature of hot element 44 by 200°F. A 200°F increase in temperature raises hot wire element 44's resistance by 5 Ohms. The ratio of the hot wire resistance at the increased temperature to the total resistance in resistor network 504 forms a 50% voltage divider network. Thus, the plus and minus pins 512 and 516 of op-amp 506 are at the same voltage since both networks 502 and 504 form 50% voltage divider networks. Thus the temperature of hot wire element 44 is forced to approximately 270°F.

**[0038]** The circuit 500 provides an output on line 518 to an electronic engine control module (not shown) which determines the proper air fuel ratio for optimal engine operation, as well known in the art. Since it takes a quarter watt as disclosed above for voltages on plus and minus pins 512 and 516 to be equal, the voltage across the hot wire element 44 and resistor 514 can be calculated using the equation:  $\text{Power} = (\text{voltage})^2 / \text{resistance}$  and then solving for voltage (V):  $V = (\text{power} \times \text{resistance})^{1/2}$  or  $(0.25 \times 25)^{1/2}$ . Since the voltage across resistors in series add the nominal output of the circuit is 5 volts for no air flow. Obviously, more circuitry would be used to level shift and amplify the output of the circuit 500.



**[0039]** As air flows over hot wire element 44, power in the form of heat is transferred from the hot wire element to the air. Heat removed from the hot wire element 44 causes the resistance of element 44 to decrease. Decreasing resistance causes the voltage applied to the minus pin 516 to decrease. Accordingly, the output voltage on line 518 would increase causing more power to be dissipated by the hot wire element 44. Thus, the increase in power dissipated by the hot wire element causes the temperature of element 44 to increase and return to 270°. When this temperature is reached, the voltage on pins 512 and 516 of op-amp 506 will be at equilibrium.

**[0040]** Accordingly, since the circuit regulates the resistance of hot wire element 44 the output of the circuit on line 518 is proportional to the square root of the power removed from the hot wire times two minus 5 volts, for example. Nominal power dissipated by the hot wire element 44 is one-quarter of a watt which is the amount of power needed to keep the hot wire element 44 at 270° F. Any heat removed from the hot wire is replaced by applying more power to element 44. Resistance of the hot wire is regulated to 25 Ohm thus resistance is considered to be constant. Power removed equals the power applied minus the amount needed to maintain the hot wire at 270° F. Solving the power formula for voltage:  $v = (\text{power} \times \text{resistance})^{1/2}$ , any increase in power applied to the hot wire element 44 is also applied to the 25 Ohm resistor. Therefore, the voltage necessary to compensate for power removed from element 44 is doubled.

**[0041]** For proper operation of sensor 10, the temperature of hot wire element 44 needs to be maintained at 200° F above ambient temperature. If the ambient temperature is constant there is no need for temperature correction. That is, a constant difference in temperature guarantees the same amount of power will be removed from the hot wire element 44 for a given air flow. However, when an fluid flow sensor is placed in an automobile (as shown in Figure 8), ambient air temperature is not constant. Typically, sensor 10 will be exposed to temperatures below freezing and above boiling. Thus, air flow temperatures lower than expected will cause a larger than desired output voltage and temperatures higher than expected will cause a lower than desired output voltage.

**[0042]** The present invention provides temperature correction to compensate for the variable ambient temperature environment present in an automobile. Temperature correction is achieved through the use of the cold wire element 46. The cold wire element 46 is placed in resistor network 502 in place of resistor 510, as illustrated in Figure 3. Circuit 500 uses cold wire element 46 for temperature compensation. Element 46 is supported by housing 12 and is placed in the air stream outside of flow passage 40. Placing cold wire element 46 in the air stream allows the circuit to quickly respond to changes in the ambient air temperature. The temperature of cold wire element 46 will follow the temperature changes of the incoming air. Since the resistance of the cold wire element (500 Ohms) is relatively large compared to the voltage drop across the element, the power dissipated is very small. For example, at 70° F the resistance of element 46 is 500 Ohms with a voltage drop of 2.5 volts. Moreover, the power dissipated by element 46 is 0.0125 watts which results in a temperature increase of about 10° F.

**[0043]** Accordingly, the resistance of the cold wire element 46 would increase by 5 Ohms and resistor network 502 resistance ratio would change. For example, the voltage applied to plus pins 512 would equal 505/1005 or 50.25% of the output voltage on line 518. In turn resistor network 504 will also have to form a ratio equal to 50.25% of the output voltage. Thus, to form the same ratio, the hot wire resistance would need to be maintained at 25.25 Ohm to develop the same resistance ratio of 50.25% thus the hot wire element 44 will be maintained at 200° above the cold wire element 46 or 280°F if the ambient temperature is 70°F. Cold wire element 46 is 10° above the ambient temperature of 70°F. Thus, the temperature difference that is necessary for handling environmental extremes is maintained. The nominal output of this circuit is still five volts. It takes 1/4 watt of power to raise the temperature of the hot wire element by 200° degrees Fahrenheit. Solving the power equation for current (i),  $i = (\text{power}/\text{resistance})^{1/2}$ . Thus, current in the hot wire network equals .099503 amps  $((0.25/25)^{1/2})$ . The output voltage is then  $(0.099503 \times 50.25)$ , which is approximately five volts. The circuit in Figure 3 can dynamically adjust to ambient air temperature changes because the change in the cold wire network is directly proportional to the properties of the hot wire network.

**[0044]** The values for resistance and changes in resistance are solely for explanatory purposes and other values certainly may be used.

**[0045]** Referring now to Figures 4a and 4b, a perspective view of housing cover 14 is further illustrated, in accordance with the present invention. Figure 4a is an inside view of housing cover 14 and Figure 4b is an outside view of housing cover 14. Housing cover 14 is fixedly joined to housing 12 (as shown in Figure 4c) along a protruding ridge 60 and 62. Ridge 60 protrudes from an inside surface 64 of housing cover 14 and matingly seals with channel 50 disposed on an inside surface 52 of housing 12. Ridge 62, protruding from an inside surface 64 of housing cover 14, matingly seals with channel 54 disposed within surface 52 and around the perimeter of flow passage 40, thus creating an enclosed and sealed flow passage 40. Housing cover 14 further includes a window aperture 66 for providing access, during manufacture, to integrated circuit 32 (as shown in Figure 4c). For example, window aperture 66 provides access to integrated circuit 32 during the calibration step in the manufacturing process. Further, as shown in Figure 4c, integrated circuit 32 is wire bonded using wire bonds to various terminal and/or bonding pads disposed on housing 12.

**[0046]** As shown in Figure 4b a channel 68 is provided around a perimeter of window 66 to matingly seal the secondary housing cover 16 to housing cover 14. Further, a side opening 70 allows air exiting flow passage 40 to flow out of both side surfaces 72 and of cover 14. A ramped portion 75 is included in surface 72 to funnel and direct air passing over the surface toward cold wire element 46

**[0047]** A perspective inside view of secondary housing cover 16 is illustrated in Figure 5. Cover 16 includes a perimeter ridge protrusion 80 which matingly seals with housing cover 14 along the perimeter of window 66 and within channel 68. Secondary housing cover 16 is substantially flat and maybe constructed of a heat conductive material, such as a metal for dissipating heat generated by integrated circuit 32. As shown in Figure 1, secondary housing cover 16 has a generally planar outside surface 84. After cover 16 is positioned on housing cover 14, both the cover 14 and the secondary housing cover 16 create a longitudinally extending and

generally planar surface to insure minimal disturbance of the air flowing around sensor 10.

**[0048]** A perspective inside view of electronics cover 18 is illustrated in Figure 6. In an embodiment of the present invention integrated circuit 32 is bonded to cover 18 and the resulting circuit and cover assembly is loaded into and matingly seals against housing 12. Cover 18 has a protruding ridge 83 rising from a surface 85 of cover 18. Protruding ridge 83 sealingly mates with a corresponding channel (not shown) disposed on housing 12 to create a weather resistant sensor housing. Preferably, cover 18 functions as a heat sink to draw heat emanating from circuit module 32. In an embodiment of the present invention, heat sink 18 is made from a metallic material or other material having similar thermal conductive properties.

**[0049]** A perspective view of a fully assembled mass fluid flow sensor 10 is illustrated in Figure 7a, in accordance with the present invention. A flange 90 is integrally formed in housing 12 and includes a plurality of mounting apertures 92 and 94. Mounting apertures 92 and 94 receive fasteners (not shown) such as screws for securing sensor 10 to a mounting surface. Further, flange 90 has a mating surface 96 for matingly engaging an engine air intake duct 304 (shown in Figure 8) as will be described below. Gasket 20 which is configured to engage a flange ledge or shelf 98 is positioned between the engine intake duct and flange 90 to provide an air tight seal between mass fluid flow sensor 10 and air intake duct 304.

**[0050]** As illustrated in Figure 7a, air flows into inlet 38 of mass fluid flow sensor 10 in a direction, as indicated by arrow i, and out of outlet 42 in a direction, as indicated by arrows O. Inlet 38 is generally circular and as illustrated in Figure 7b has a generally elliptical cross-section.

**[0051]** With specific reference to Figure 7b, elliptical surfaces 200 which define the perimeter of inlet 38 and nozzle 39. Moreover, as shown, elliptical surfaces 200 converge along a longitudinal axis 202, creating an inlet and nozzle having a longitudinally converging elliptical surface. This inlet and nozzle configuration is known as a jet nozzle. Further, it is known that this jet nozzle configuration creates a critical area, at the exit of the nozzle, having a uniform fluid flow velocity. As stated above the present invention has improved accuracy as

compared to the prior art because, for example, the hot element 44 is located in the critical area and therefore is evenly cooled by incoming fluid.

**[0052]** Referring now to Figure 8, an exemplary automotive environment in which a mass fluid flow sensor may be operatively disposed is illustrated, in accordance with the present invention. Typically, an automotive vehicle has an air intake manifold 300 for supplying fresh air to the vehicle's engine (not shown). Generally, air intake manifold 300 includes a filter 302 for filtering the intake air and extract contaminants from the air drawn into manifold 300.

**[0053]** Air intake manifold 300 is typically attached to an air duct 304 for communicating the clean air to the vehicle's engine. As illustrated, mass fluid flow sensor 10 is positioned and fixedly secured to air duct 304 through an aperture 306 in air duct 304. Outside air is drawn into intake manifold 300 in a direction indicated by arrow A and flows through manifold 300 as indicated by arrows A' and A''. When the intake air reaches air duct 304, a portion of the intake air flows into the mass air flow sensor, as indicated by arrow i, and then out of the mass fluid flow sensor as indicated by arrow o. All of the intake air eventually exits air duct 304 and enters the vehicle's engine, as indicated by arrow e. Electrical control signals containing information regarding the amount of air flowing through the air duct 304, derived from measurements and processing carried out on integrated circuit 32, is communicated to the vehicle's electronic control systems through a connector 308 and wire harness 310.

**[0054]** The present invention contemplates an assembly and/or manufacturing method or process for constructing mass fluid flow sensor 10. In an initial step the resistive elements are electrically connected to the housing using solder or other like material. At a next step, the electronics cover 18 and integrated circuit 32 assembly is mounted to the housing 12, using an adhesive or similar material. At a next step, the housing cover 14 is mated to housing 12 and bonded thereto using an adhesive or similar material. At a next step, the assembly is placed in an oven or other environment suitable for curing the adhesive. At a next step, the integrated circuit 32 is wire bonded to terminals and/or bonding pads on housing 12. At a next step, the integrated circuit 32 is calibrated and/or adjusted and/or resistors disposed within

circuit 32 are trimmed. At a next step, the secondary housing cover 16 is mated to housing 12 and bonded thereto using an adhesive or similar material. At a final step, sensor 10 is tested to insure proper function at different operating states and environmental conditions.

**[0055]** The foregoing discussion discloses and describes a preferred embodiment of the invention. One skilled in the art will readily recognize from such discussion, and from the accompanying drawings and claims, that changes and modifications can be made to the invention without departing from the true spirit and fair scope of the invention as defined in the following claims.